Impact of spacing and rotation length on nutrient budgets of poplar plantations for pulpwood[1)]

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Abstract The above-ground biomass and nutrient accumulation by poplar plantations were evaluated for pulpwood production in China. Experimental treatments applied in a split-plot design included four planting densities (1111, 833, 625 and 500 stems·hm^{-2}), three rotation lengths (4a, 5a and 6a) and three poplar clones (I-69, NL-80351 and I-72). The highest biomass was achieved in the highest stocked stand (1111 stem·hm^{-2}) at 6 of rotation age for both clone I-69 and clone I-72, which is about two times that in the stands of 500 stems·hm^{-2} at 4 of rotation age. However, the highest occurred in the stand of 833 stems·hm^{-2} at 6-year rotation for NL-80351. Ranking of the plantation biomass production by component was stem > branches > foliage > stem-bark and the production of the support components of the plantation was 10-fold that of the productive component, i.e., foliage. The pattern of accumulation of nutrients by the plantations was similar to the biomass. Nutrient accumulation in the plantations was in the order of Ca > N > K > Mg > P, but some differences existed in annual nutrient accumulation rates for four planting densities and three poplar clones. The mean annual accumulation of N and P in the plantations was 13.2 and 2.8 kg·hm^{-2} in stem, 12.1 and 1.9 kg·hm^{-2} in branch, and 98.5 and 9.5 kg·hm^{-2} in foliage. The mean Ca, K and Mg accumulations were 28.2, 18.5 and 2.9 kg·hm^{-2}·a^{-1}, 26.9, 11.0 and 2.3 kg·hm^{-2}·a^{-1} in branch, and 116.5, 81.3 and 16.1 kg·hm^{-2}·a^{-1} in foliage, respectively. Biomass utilization standards markedly affected the export of nutrients from the site. Whole tree utilization yields the most biomass and removes the most nutrients. Removal of stem with ≥ 10-cm diameter exports about half of the biomass, but N and nutrients removals are only 23% and 28% of the total, respectively. Removal of the entire stem provides about two-thirds of the total biomass and removes 31.1% total N and 37.5 % total nutrients respectively. Including the branches in the removal increases biomass yield to 92% of the total, and nutrient removal is about 68% of the total.

Keywords: Poplar plantation, Biomass productivity, Nutrient content, Nutrient accumulation and removal,

Introduction

Poplars have many characteristics suitable for plantation culture as compared to other forest species, such as fast growth, adaptability to different environmental conditions and to different silvicultural systems, which enable the production of large quantities of wood in short periods of time. Poplars can be used for different forms of processing in timber industry, as well as in pulp and paper industry and as a source of energy (Gambles & Zsuffa 1984; Moran & Nautryal 1985; Fang *et al* 1993). Since some poplar clones were introduced in the 1970`s, poplars have been the major tree species both in the plantation forestry and in agroforestry systems throughout the south temperate central area of China, including all or portions of Jiangsu, Anhui, Zhejiang, Hubei, Henan, Shandong and Shanxi provinces, an area of roughly about 600000 km^2 (Xu *et al* 1989; Fang *et al* 1997). Poplar plantations require rigorous site preparation, genetically improved planting stock, short rotations and occasional fertilization (Shelton *et al.* 1982; Xu & Fang 1997). Nutrient content of poplar trees is high relative to that of other tree species, and preliminary studies of growth-nutrient relationships have demonstrated the importance of nutrient status in stand development (Shelton *et al.* 1982; Fang *et al.* 1996). The nutrient removals incurred by cropping plantations also may be high and may influence the nutrient status of a site for subsequent productivity.

Published results of research indicate that the intensive management and cropping techniques employed with poplar plantations require understanding of the nutrition requirements of these systems, especially with their continued use in subsequent rotations. Therefore, this study was designed with the primary objective of assessing the biomass and nutrient content for poplar plantations with different clones, growing spaces and rotation lengths. This assessment enables us to estimate growth, biomass and nutrient removals for short rotations envisioned for poplar plantations.

[1)]This paper is a part of " Selection and culture of new varieties for poplar industrial forests" which is one of national key tasks in the Ninth Five-Year Plan.

Received: 1999-04-30
Responsible editor: Chai Ruihai

Methods

Study area

The study area was located at Hanyuan Forestry Farm (33°08′N, 119°19′E), Baoying County, Jiangsu Province, China. The area has a warm temperate climate with a mean annual precipitation of 964 mm. The frost-free period is about 229 days every year, and the radiant intensity on average is 494.04 KJ/cm^2. Mean annual air temperature is 14.3 °C and average temperatures are 0.4 °C in Jan. and 27.6 °C in July. The study area is on a drainage adjacent to Baoying Lake and the landform belongs to the bottomland of Lixia River. Prior to planting, the soil is clay loam of moderate fertility. The organic matter content is about 0.84%, pH value 7.8, total nitrogen content 0.064%, available P and K contents 1.76 mg/kg and 67.57 mg • kg^{-1} respectively, and the Ca and Mg contents are 0.29% and 0.06% respectively. The water table of soil is about 1.0 m and the bulk density of soil from surface depth to 1.0 m is 1.35 g • cm^{-3}.

Experiment treatments

The trial was established in 1992 with one-year-old seedlings. The total area of the experiment stand is about 27.0 hm^2. A split-plot randomized block design was used to establish four planting densities in three blocks, three poplar clones in split-plots, and three rotation lengths in split-sub-plots, giving 108 sub-plots. The area of each sub-plot was about 2500 m^2.

The four planting densities were 1111 stems • hm^{-2} (spacing: 3 m × 3 m), 833 stems • hm^{-2}(spacing: 3 m × 4 m), 625 stems/hm^2 (spacing: 4m × 4 m) and 500 stems • hm^{-2} (spacing: 4 m × 5 m). The three poplar clones were clone I-69 (*Populus deltoides* Bartr. cv. Lux'), clone I-72 (*P. × euramericana* (Dode) Guinier cv. San Martino') and clone NL-80351, a hybrid of clone I-69 × clone I-63 (*P. deltoides* Bartr. cv. Havard'). The three rotation lengths were four years, five years and six years.

Procedures

The mean-tree technique was used to assess the above-ground biomass and nutrient content of the poplar plantations. This technique involves destructive sampling of trees that best represent the mean size of a plantation and uses the number of trees in the plantation to expand mean-tree values to an area basis.

Sample tree selection

The selection of sample tree was based on the multiple characteristics, i.e. the mean DBH of the plantation and on the means of total height and crown dimensions. Diameters at 1.3-m height of all trees on each plot were measured annually. The total height, crown width and crown height were measured for all trees within 15% of the mean DBH for each plot. The single tree closest to the means of DBH, height and crown features of each plot and with good form and vigour was selected for destructive sampling.

Destructive sampling

Each sample tree was cut at ground level in August or September in 1995, 1996 and 1997 respectively (each year 12 sample trees) and was divided into four components: stem, bark, branches and foliage. The stem was severed into 2.0-m bolts, and stem and bark samples were obtained from disks cut from the center of each bolt. The branches were divided into older branches, branches of intermediate age, current branches and dead branches. Green weights of all components were determined in the field, and samples were collected for moisture and chemical analysis. Total above-ground biomass and nutrient content of the stem components were obtained by summing the values for all bolts of each sample tree. Likewise, the values for the branch component were a summation of the four branch categories.

Merchantable biomass

Equations for predicting the fraction of total stem biomass and stem biomass that is merchantable to any diameter limit for cottonwood were developed in 1982 by Shelton et al. And those equations were used to predict the merchantable inside-bark and outside-bark stem and stem biomass to any diameter limit in this paper.

Net primary productivity

Total net primary productivity was the sum of the standing crop, which did not include cumulative foliage production, the quantity of branches shed in natural pruning, the production of reproductive material and losses to insects. Only the above ground productivity was estimated.

Laboratory analysis

Tissues, previously dried at 70°C for dry weight determination, were prepared for chemical analysis by grinding to pass a 20-mesh sieve. Total nitrogen (N) for the wood tissue was determined by a macro-Kjeldahl procedure, and a semimicro-Kjeldahl procedure was used for the other tissues. The ground tissues were dry ashed at 500°C for 4 h. Total phosphorus (P) was determined by the vanadomolybdate procedure (Jackson, 1958), and potassium (K), calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectroscopy (Issac and Kerber 1971).

Nutrient content

Nutrient content of the sample tree was calculated from the values for biomass and nutrient concentrations. The nutrient content of the unmerchantable stemtop was determined by summing the values for bolts smaller than the merchantability limit (i.e., 5, 8 and 10 cm). The content of the fractional portion of bolt was determined by interpolation. The procedure used to obtain plantation biomass was also used to expand the nutrient content of sample tree to a plantation basis.

Result and discussion

Plantation biomass and distribution pattern

Above-ground plantation biomass production and distribution patterns were showed in Fig. 1. Ranking of the plantation biomass production by planting density was 1111 stems • hm^{-2}> 833 stems • hm^{-2} > 625 stems • hm^{-2}> 500 stems • hm^2 for three poplar clones and three rotation lengths, with the exception of clone NL-80351 at six years. For clone I-69 and clone I-72, the highest biomass was achieved in the stand of 1111 stems • hm^{-2} at age six, 78.381 t • hm^{-2} and 71.826 t • hm^{-2} respectively. However, for clone NL-80351, the highest occurred in the stand of 833 stems •hm^{-2} with six-year rotation, 75.769 t •hm^{-2}. The lowest biomass production happened if the planting density was 500 stems • hm^{-2} and rotation length was four years, 35.285 t • hm^{-2} for clone NL-80351, 33.795 t •hm^{-2} for clone I-69 and 28.650 t •hm^{-2} for clone I-72. As to the three poplar clones, the biomass productivity of clone NL-80351 was slightly higher than that of clone I-69 and clone I-72 was the lowest.

Ranking of the plantation biomass production by components was stem > branches > foliage > bark. Production of the support components of the plantation (i.e., stem, bark and branches) was more than 10-fold that of the productive component (i.e., foliage), and this distribution did not change significantly over the age span of this study. But the distribution pattern was changed as spacing increased, i.e., more dry matters were distributed to foliage and branches and less to stem and bark. The quantity of foliage per unit of branches changed with time. This is best illustrated by the pattern of production of current branches and foliage.

ANOVA results indicated that there were significant differences ($p<0.01$) in both above-ground biomass production and its component productions for rotation length treatments, the longer the rotation, the higher the productivity. For three poplar clones, the differences were significant in above-ground biomass, branch and foliage productions, but not significant in stem and bark productions. With the exception of plantation foliage production, significant differences existed in both above-ground biomass and its component productions for four planting density treatments.

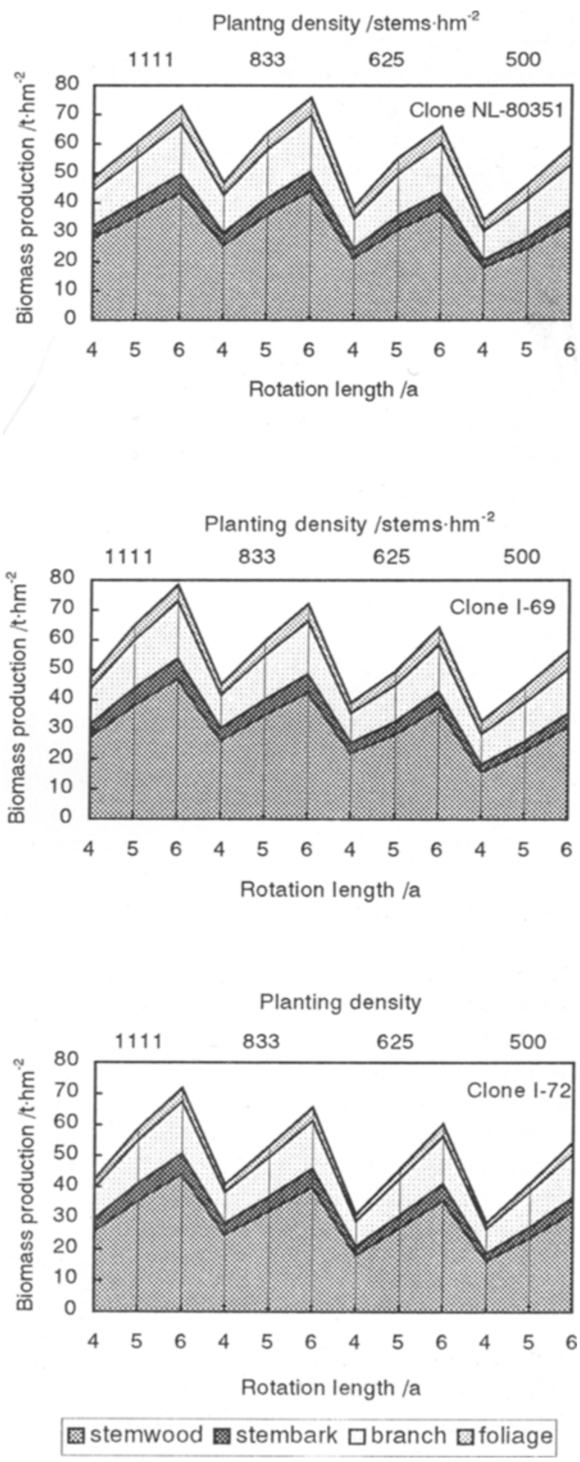

Fig. 1. Relationship among plantation biomass, distribution patterns, planting densities and rotation lengths for three poplar clones

Plantation nutrient content

The pattern of accumulation of nutrients by the plantations was similar to biomass (Table 1). The primary difference was in the distribution among components. The'highest nutrient accumulation was achieved in the stand of 1111 stems • hm^{-2} at age six for clone I-69 and I-72, which was about 50% higher than that of the plantation with 500 stems/hm^2 at age four. However, the nutrient accumulation in the plantation with 833 stems • hm^{-2} was slightly higher than that of the plantation with 1111 stems • hm^{-2} at six years for clone NL-80351, both about 45% higher than that in the stand of 500 stems • hm^{-2} with four year rotation. Compared with the clone I-69, the nutrient accumulation increased by an average of 4.1% for clone NL-80351 and decreased by an average of 16.3% for clone I-72.

Table 1. Total nutrient accumulation (N, P, K, Ca and Mg) in the plantations with different treatments (kg • hm^{-2})

Combination Type*	Planting density /stems • hm^{-2}	Rotation /a	NL-80351	I-69	I-72
1	1111	4	791.36	754.37	623.94
2	1111	5	951.80	1004.37	771.13
3	1111	6	1118.44	1183.51	1041.31
4	833	4	783.25	721.72	609.08
5	833	5	988.57	922.93	752.41
6	833	6	1196.62	1125.52	971.20
7	625	4	694.10	647.19	474.80
8	625	5	929.39	810.81	730.81
9	625	6	1063.71	970.80	898.34
10	500	4	632.82	641.69	445.55
11	500	5	853.70	818.94	694.39
12	500	6	972.22	943.61	808.75
Mean value			914.67	878.79	735.14

*Combination type means the plantations with different densities and rotation lengths, such as Combination type 1 refers to the stand with stems • hm^{-2} and 4-years rotation.

Nutrient accumulation in the plantations was in the order of Ca > N > K > Mg > P, and averaged 171.6, 123.5, 110.5, 21.2 and 14.1 kg • hm^{-2} • a^{-1} from four to six years. Annual accumulation of Ca in the plantations was about 1.4 times of N, 1.6 times of K, 8.1 times of Mg and 12.2 times of P respectively. However, there were some differences in annual nutrient accumulation rates for four planting densities and three poplar clones.

Clone NL-80351 is considered here as an example of nutrients accumulation pattern for the components in the plantations (Fig. 2). Accumulation of N, K and Mg was highest in the foliage. The maximum accumulation of Ca was in the branches. However, P accumulation in the plantation was changed over the planting density variation, the highest in the stem when the planting density was 833 stems·hm^{-2} or more, otherwise the greatest in the foliage. The different nutrient accumulation patterns resulted from the variation in nutrient concentration and biomass productivity of plantations among components. Generally, the stem components accumulated nutrients exponentially through time, and nutrient accumulation in the crown components was liner.

The mean annual accumulation of N and P in the plantations was 13.2 and 2.8 kg • hm^{-2} in stems (including stem and bark), 12.1 and 1.9 kg • hm^{-2} in branches, and 98.5 and 9.5 kg • hm^{-2} in foliage from four to six years respectively. Total N accumulation in branches and stems was about 26.5, 28.6, 24.7 and 21.3 kg • hm^{-2} • a^{-1} respectively for four planting densities (from 1 111 to 500 stems • hm^2), which was about 5.4 times of total P. The foliage N and P have two fates; 60% is translocated to the permanent tissues before abscission, and 40% returns to the forest floor via litterfall (Baker & Blackmon 1977). The annual return of nutrients via litterfall was about 39.4 kg • hm^{-2} for N and 3.8 kg • hm^{-2} for P. Total N transferred through the litter chain was approaching about 150.0 kg • hm^{-2} for 4-year rotation, 190.0 kg • hm^{-2} for 5-year rotation and 230.0 kg • hm^{-2} for 6-year rotation. However, this total does not represent an actual quantity, because the same unit of N may be repeatedly cycled through the litter chain.

The mean Ca, K and Mg accumulations in the plantations were 28.2, 18.5 and 2.9 kg • hm^{-2} • a^{-1} in stems, 26.9, 11.0, and 2.3 kg • hm^{-2} • a^{-1} in branches, and 116.5, 81.3 and 16.1 kg • hm^{-2} • a^{-1} in foliage, respectively. Ca, K, and Mg are not translocated before abscission (Baker & Blanckmon 1977), and the entire foliage contents of the stand crop is transferred each year to the forest floor through litterfall at rates of about 116, 81, and 16 kg • hm^{-2}. The current annual increment (CAI) of above-ground biomass and nutri-

ents was different among various treatments, and the allocation of the total increment among the components differed for biomass and nutrients. For example, the annual increment of biomass was greatest for stem, while the annual increment of nutrients was greatest in foliage.

CAI of nutrients approximates the annual nutrient requirement, and these are illustrated by foliage. A portion of the N and P in foliage is translocated before leaf abscission and stored in the permanent tissues, and only supplemental N and P must be obtained from the soil to meet the requirements of foliage the next year. In contrast, translocation of K, Ca and Mg from foliage is virtually nil, and the annual requirement for these nutrients must be obtained from soil.

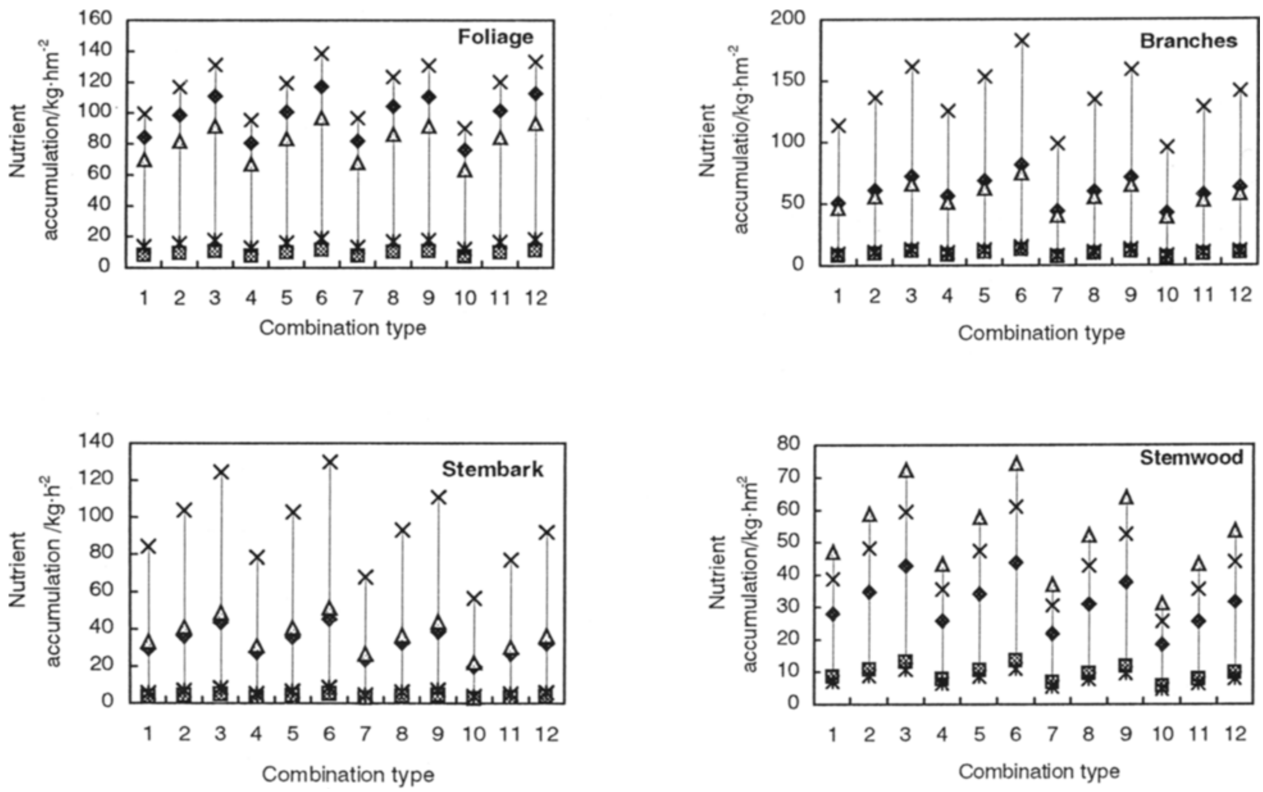

Fig. 2. Nutrient distribution patterns in various components for clone NL-80351 (Combination type see Table 1).
◆--N; ■--P; Λ--K; ×--Ca; Ж--Mg

Management implications

Spacing and rotation length

Three common rotation lengths with poplar are minirotations for bioenergy, mid-rotations for fibre production and short rotations for veneer (Gambles & Zsuffa 1984). A comparison of three rotation lengths and two levels of utilization were developed for this study (Table 2).

Mean annual yields of stem-only, and woody biomass (stem + branches) utilization were about the same at 5-year rotation and 6-year rotation. However, yields for stem-only and woody biomass utilization were 12.9% and 10.7% higher at 6-year rotation than at 4-year rotation respectively, because branches constitute a relatively higher percentage of total biomass in the 4-year rotation. Mean annual yield of woody biomass utilization is about 36.0% higher than that of stem-only utilization.

Nutrient removals for stem-only, and woody biomass utilization did not differ appreciably for the 5-year and 6-year rotations, which are about 10.0% and 9.3% higher than those of 4-year rotation, respectively. Nutrient removals were about 89.0% less for N, 67.0% for P, 60.0% for K, 93.0% for Ca and 75.0% for Mg with stem-only utilization than with woody biomass utilization, respectively. Some research results showed that nutrient removals for whole tree utilization were less for long rotation (18-year rotation) than for short rotation (9-year rotation), by 30% for N, P and K and 20% for Ca and Mg; and for stem-only utilization, long rotations remove 15% less N, P and K than short rotations and 10 % Ca and Mg (Shelton *et*

al. 1982). Probably the difference in removal of the mobile and immobile nutrients is partially duo to changes in their concentration in the stem as age increases.

Table 2. Mean annual removals of biomass ($t \cdot hm^{-2}$) and nutrients ($kg \cdot hm^{-2}$) for three rotation lengths of clone I-69 under two utilisations*

Item	4-year Rotation		5-year rotation		6-year rotation	
	Stem-only	Stem & branch	Stem-only	Stem & branch	Stem-only	Stem & branch
Biomass	7.928	10.919	8.841	11.979	8.948	12.087
N	14.301	27.118	15.562	29.434	15.820	29.611
P	3.007	5.054	3.297	5.513	3.366	5.566
K	19.903	31.542	21.730	34.328	22.134	34.640
Ca	30.729	59.313	33.234	64.176	33.687	64.400
Mg	3.164	5.573	3.451	6.059	3.513	6.102

*The planting density was 1111 stems/ha.

Spacing in cottonwood plantations in the United States generally range from 140 to 2000 trees • hm^{-2}, and even wider spacing are used in Europe (FAO, 1979). The closer spacing generally are linked to short rotations for energy, forage and fibre production, and wider spacing are associated with longer rotations for producing sawlogs and veneer. There is no best spacing for all products. However, stands of about 750 trees • hm^{-2} have been suggested as a good compromise in the production of pulpwood, growth of potential crop trees and tree quality (Krinard and Johnson 1980), and stands of about 278 or 204 stems • hm^{-2} without thinning within the 12-year rotation have been developed for plywood production in China (Lu *et al.* 1989).

The optimum combination between spacing and rotation lengths depends on the products, site quality and silvicultural practices (Fang *et al.* 1993). This study indicated that the fraction of total weight occurring from the stem base to the 10-cm diameter limit increased as the planting density reduced and rotation prolonged (Table 3). The fraction is 0.602 for the stand of 1111 stems • hm^{-2}, 0.694 for the stand of 833 stems • hm^{-2}, 0.752 for the stand of 625 stems • hm^{-2} and 0.783 for the stand of 500 stems • hm^{-2} at 4-year rotation, while the fraction was 0.602 at 4-year rotation, 0.669 at 5-year rotation and 0.752 at 6-year rotation for the stands of 1111 stems • hm^{-2}. The results suggested that the combination between planting density of 1111 stems • hm^{-2} and 6-year rotation could achieve the highest stem and merchantable biomass for pulpwood production, otherwise prolonging the rotation length or increasing planting density is required. The results also indicated that selecting some clones or cultivars of cottonwood, such as clone I-69 and clone NL-80351, is better than that of euramerican hybrid clones (clone I-72) for pulpwood production because cottonwood clones generally grow quickly in early stage, which is suitable for short rotation management systems.

Table 3. Mean annual production of stem biomass and merchantable stem biomass for clone I-69 ($t \cdot hm^{-2} \cdot a^{-1}$)

Density	4-year rotation		5-year rotation		6-year rotation	
	Stem	Stem1*	Stem	Stem1	Stem	Stem1
1111	7.928	4.774	8.841	5.917	8.948	6.732
833	7.607	5.283	7.836	5.844	8.112	6.599
625	6.430	4.835	6.510	5.412	6.674	5.815
500	4.749	3.571	5.221	4.579	5.493	5.087

*Merchantable stem biomass with 10 cm diameter limit.

Biomass utilization and nutrient removal

Changing utilization standards markedly affected the export of nutrients from a site. Whole-tree utilization yielded the most biomass and removed the most nutrients. More conservative utilization remove specific portions of the standing crop and remove less nutrients. The general relationship for these plantations was typified by N and total nutrients (N, P, K, Ca and Mg). The percentage of total nutrient removal was slightly higher than that of the N (Fig. 3).

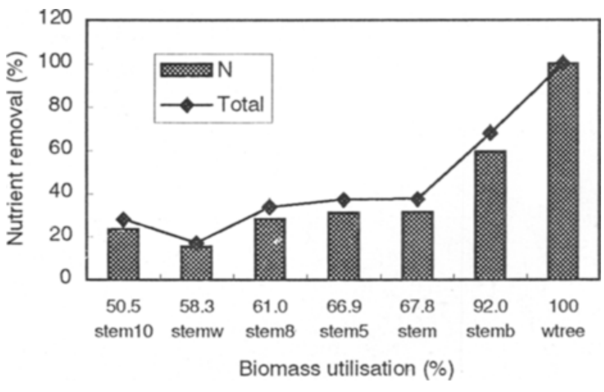

Fig. 4. The relationship between biomass utilisation and nutrient removals.

Note: Stem10--stem biomass of ≥10-cm diameter; stem8--stem biomass of ≥8-cm diameter; stem5--stem biomass of ≥5-cm diameter; stemb--biomass of stem & branches; stemw--stem biomass; wtree--whole tree biomass.

Removal of the entire stem provided about two thirds of the total biomass and removed 31.3% total N and 37.5% total nutrients respectively. Including the branches in the removal increased biomass yield to 92% of the total, and N and nutrients removal were about 60% and 68% of the total respectively. If foliage was included in removal, the biomass yield would increase only about 10%, but the removal of N would increase by 40%. Removal of foliage can be avoided in whole-tree utilization by postponing harvest until after defoliation. However, such a delay is only partially effective for N and P, because much of the foliage content is translocated to the permanent tissue before abscission.

Removal of stem provided about 60% of the total biomass, and removed the least nutrients, only about 15% of the total N and 17% of the total nutrients respectively. This utilization involves debarking the stem on the site, which is almost impossible with current management systems in China. The normal harvest practice for poplars is removals of stem and branches or only removal of stem with diameter≥10 cm in China.

Maintenance of productivity

The ability of site to sustain nutrient removals from cropping is a basic consideration in evaluating various intensities of utilization. Maintenance of the site productivity involves all compartments of the forest ecosystem and the nutrient fluxes among the compartments (Kimmins 1977; Freedman *et al.* 1981; Smith *et al.* 1994). Therefore, the nutrient inputs, losses and reserves of the system must be quantified.

The primary objective of impact studies to examine forest nutrient budget is to assess and predict the consequences of specific management practices on site productivity. Researchers dealing with this topic are reluctant to reach definitive conclusions and recommendations because of the problems associated with quantifying the dynamic components of the nutrient cycles in forest ecosystems. Accurate values of the rates, fluxes, and pools of nutrients involved in the critical processes of mineralisation, immobilisation, leaching, weathering, and fixation are difficult and costly to measure precisely, especially in the short term (Kimmins 1977).

An estimate of the ability to sustain productivity under various cropping systems in research area is obtained from the nutrient requirements determined by this study, the nutrient status of the site and the atmospheric nutrient inputs. Total N, available P, exchangeable K, Ca and Mg in the research site to a depth of 100 cm are 8.645, 0.581, 1.465, 39.150 and 8.100 $t \cdot hm^{-2}$, respectively. These nutrient supplies are supplemented with atmospheric inputs that average 10.0, 1.0, 4.0, 6.0 and 1.5 $kg \cdot hm^{-2} \cdot a^{-1}$ for N, P, K, Ca and Mg, respectively (Shelton *et al.* 1984). Additional gains and losses include erosion, leaching, mineral weathering, deposition from floods and N fixation. Little or no data exist for these quantities for this locale; therefore, these fluxes are ignored in this initial approximation.

Nutrient losses relative to site nutrient capital are given in Table 4 for harvesting stem and branches, stem-only and stem which top diameter is more than 10 cm under a steady-state model of ecosystem dynamics. The values for potential depletion are lowest for the most conservative management system (low planting density, and top diameter of stem ≥10-cm utilization) and highest for the most intensive (stem and branch utilization, and high planting density). In addition, the values vary among the nutrients, with Mg having the lowest values and K the highest. These values, with the possible exception of K, indicate no problems with soil depletion over a number of rotations (6-year rotation length). Thus, K appears to have the height potential for depletion. However, the chemistry of soil K suggests that the amount of K that can be used by plants is underestimated by standard analytical procedures. K reserves in the soil exist in both readily and slowly available forms. Exchangeable K, the common expression of soil K, does not include the slowly available K. Therefore, the potential for K depletion is not great when the release properties of the soil are considered.

Table 4. Nutrient loss from sites as a percentage of soil nutrient reserves for clone I-69 at 6-years rotation (%)

Nutrient	Utilization	Planting Density/ stems• hm^{-2}			
		1111	833	625	500
N	Stem+branch	2.05	1.87	1.55	1.35
	Stem-only	1.10	1.00	0.80	0.67
	≥10 cm Stem	0.83	0.81	0.70	0.62
P	Stem+branch	5.75	5.23	4.35	3.75
	Stem-only	3.48	3.15	2.59	2.13
	≥10 cm-stem	2.62	2.56	2.26	1.97
K	Stem+branch	14.19	12.91	10.70	9.21
	Stem-only	9.07	8.22	6.74	5.55
	≥10 cm Stem	6.82	6.68	5.87	5.14
Ca	Stem+branch	0.99	0.90	0.75	0.65
	Stem-only	0.52	0.49	0.38	0.31
	≥10 cm-stem	0.39	0.38	0.33	0.29
Mg	Stem+branch	0.45	0.41	0.34	0.30
	Stem-only	0.26	0.24	0.19	0.16
	≥10 cm-stem	0.20	0.19	0.17	0.15

There appears to be little potential for soil depletion on the research site in the immediate future, especially if conservative utilization practices are employed. However, the sufficiency periods will be dramatically reduced if rotation ages are shortened

and spacings are reduced by modern silvicultural means without using fertilization. So additional research is needed to provide an overall picture of relationship of nutrition to productivity and the influence of intensive culture on the physical properties of the soil.

Acknowledgements

We acknowledge the financial support of the Chinese National Foundation for Research Science and Technology. Numerous people associated with Nanjing Forestry University, contributed to this study, including Guibin Wang, Yixuan Wang, Xinshou San, Jun Liang, Xiang Yu, and others. The authors are grateful to C.T. Smith and A.T. Lowe at the New Zealand Forest Research Institute for their review and comments.

References

Baker, J.B., Blackmon, B.G. 1977. Biomass and nutrient accumulation in a cottonwood plantation--the first growing season. Soil Sci. Soc. Am. Jour., **41**: 632-636.

Fang Shengzuo, Lu Shixing, Xu Xizeng, *et al.* 1997. A case study on agroforestry management systems: effects of new poplar-crop interplanting patterns on biomass productivity, crop quality and economic benefits. Pp.71-78 in: Volume 1. Forest and tree resources", Proceedings of the XI World Forestry Congress, Antalya, Turkey 13-22 October 1997.

Fang Shengzuo, Xu Xizeng, San Xinshou, *et al.* 1996. The biomass productivity and wood quality of eastern cottonwood in minirotation management systems. Scientia Silvae Sinicae, **32**(4): 334-341.

Fang Shengzuo, Cao Fuliang, Zhu Yijun. 1993. The present situation and prospect of short-rotation management system in poplars. Journal of Nanjing Forestry University, **17**(add.): 50-55

FAO. 1979. Poplars and willows in wood production and land use. Forestry Series No. 10. Food and Agric. Organ., Rome, 328pp

Freedman, B., Movash, R., Hanson, A.J. 1981. Biomass and nutrient removals by conventional and whole-tree clear-cutting of a red spruce-balsam fir stand in Central Nova Scotia. Can. J. For. Res., (11): 249-257.

Gambles, R.L., Zsuffa, L. 1984. Conversion and use of poplar and willow biomass for food, forage and energy in North America. International Poplar Commission, October, 1984, Room, Fo: MISC/84/15

Issac, R.A., Kerber, J.D. 1971. Atomic absorption and flame photometry: techniques and uses in soil, plant, and water analysis. Pp.17-37 in Walsh, L.M. (Ed.) Instrumental Methods for Analysis of Soils and Plant Tissues. Soil Sci. Soc. Amer., Madison, WI. 222pp

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall Englewood Cliffs, NJ. 492pp

Kimmins, J.P. 1997. Evaluation of the consequences for future tree productivity of the loss of nutrients in whole-tree harvesting. For. Ecol. Manag., (1):169-183.

Kinard, R.M., Johnson, R.L. 1980. Fifteen years of cottonwood plantation growth and yield. Southern Journal of Applied Forestry, **4**:180-185

Lu ShiXing, Xu Xizeng, Wang Mingxing. *et al.* 1989. A study on the planting density of the man-made poplar forests. in: Symposium on Techniques of Fast-growing and High Yield for Southern Type Clones of Aigeiros Section. Beijing: Academic Book & Periodical Press, Pp.72-80.

Lu Shixing, Xu Xizeng, Cao, Fuliang *et al.* 1997. A study on biomass productivity for short-rotation management of poplar clones. in: Lu, Shixing *et al* (Ed.) Research and Practice on Poplar Industrial Plantations. Beijing: China Forestry Publishing House, Pp.58-63

Moran, L.A., Nautryal, J.G. 1985. Present and future of feasibility of short-rotation energy farm in Ontario, Forest Ecology and Management, **10**: 323-328

Shelton, M.G., Switzer, G.L., Nelson, L.E., *et al.* 1982: The development of cottonwood plantations on alluvial soils. Mississippi State University, Technical Bulletin 113, 46 pp.

Smith, C.T., Dyck, W.J., Beet, P.N., *et al.* 1994. Nutrition and productivity of pinus raduata following harvest disturbance and fertilisation of coastal sand dunes. For. Ecol. Manag., **66**:5-38.

Smith, C.T., Lowe, A.T., Beet, P.N., *et al.* 1994: Nutrient accumulation in second-rotation *Pinus radiata* after harvest residue management and fertilizer treatment of coastal sand dunes. New Zealand Journal of Forestry Sciences **24**(2/3): 362-389

Xu Xizeng & Fang Shengzuo. 1997. A review of short-rotation cultivation for poplar clones. in: Lu Shixing, Fang Shengzuo., Xu, XiZeng (Ed.) Research and Practice on Poplar Industrial Plantations. Beijing: China Forestry Publishing House, Pp.1-9

Xu Xizeng, & Lu Shixing. 1989. A study on the productive capacity and economic effect of agroforestry complex. in: Symposium on Techniques of Fast-growing and High Yield for Southern Type Clones of the Aigeiros Section. Beijing: Academic Book & Periodical Press, Pp.56-71